ener$ave
For Industry
and Commerce

SAVING MONEY THROUGH PROCESS DESIGN AND HEAT RECOVERY

3

Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

88-03072/

Editorial Review Board

B. W. Robinson, Ontario Hydro

M. Bernie Zgola, Labatt Breweries of Canada Limited

Brian Howell, Consumers Glass Company Limited

N. Cuchurean, Celanese Canada Limited

A. G. Darimont, Esso Chemical Canada

B. J. Davies, Canron Limited

P. A. Mitcham, International Harvester Canada Limited

T. E. Chalmer, Canadian International Paper Company

W. J. Wolcott, General Motors Canada Limited

J. G. McGill, Hayes-Dana Limited

A. C. S. Hayden, Canadian Combustion Research Laboratory

R.C. Walterson, Thames Valley Beverages Ltd.

Contents

Introduction	2
Text	2
Case histories	16
Quick tips	28
Metric conversion	29

E1-77-10
© Minister of Supply and Services Canada 1980
Cat. No.: M91-2/3-1980E
ISBN 0-662-11149-4

Published under the authority of
Minister of Energy, Mines and Resources,
Government of Canada

SAVING MONEY THROUGH PROCESS DESIGN AND HEAT RECOVERY 3

Saving money through Process Design and Heat Recovery

Introduction:

Most of the industrial processes in Canadian plants of today were designed in a period when energy costs and attitudes toward energy usage were vastly different. As a result, many processes are tremendously energy inefficient.

This booklet is designed to help plant manager to more efficiently utilize process equipment and to retrofit insulation, controls and other equipment which will promote greater conservation of electrical and other energy.

And while heat recovery techniques cover a wide spectrum of industrial areas, many are process related. As a result, the text contains a full description of various heat recovery devices commercially available.

Process design and heat recovery

High energy costs — they're something industry has come to accept as an immutable fact of life. In fact, we've come to take them so much for granted that its sometimes hard to remember when energy costs were much lower than they are now.

But those times are not ancient history. The substantial increase in energy costs is really a fairly recent phenomenon. As late as 1972, for example, most Canadian companies were paying less than $1.00 for an Mcf of natural gas. It should come as no surprise then, that most plants, even those which can be classified as "modern" were designed with easily available, relatively low cost fuel as a basic parameter. As a result, many facets of plant energy utilization are not as energy efficient as they might be. Heating, lighting, steam systems and production planning, among other areas, all reflect an attitude towards energy and its utilization which emphasized growth without really worrying about a contribution to cost savings through conservation of energy.

Nowhere is this attitude more apparent than in the area of plant processes and equipment. Simply stated, if energy costs had been at their present levels and energy conservation had been a watchword, processes would not have been designed in the way that they were — without adequate insulation, allowing large quantities of waste heat to escape and ignoring other sources of waste heat for preheating of process materials.

There is no point in belabouring the fact that the ground rules have changed. A more productive concern is one about what can be done to rectify the situation which exists in many plant processes.

In addition, water has a large quantity of energy indirectly associated with its treatment and supply. As well, waste water often contains significant quantities of energy.

In future, water will not only be progressively more costly to procure in large quantities, it will be more costly to dispose of. Water conservation programmes can be justified now on the basis of economics (see case histories); but they will also stand companies in good stead should water "curtailment" or at least stringent supply controls become a reality.

Identifying the magnitude of the opportunity

The degree to which processes in a given plant are efficient or inefficient will depend largely on when the plant was built, when various processes were installed and the degree of energy enlightenment that was shown by engineers and designers at the time of installation.

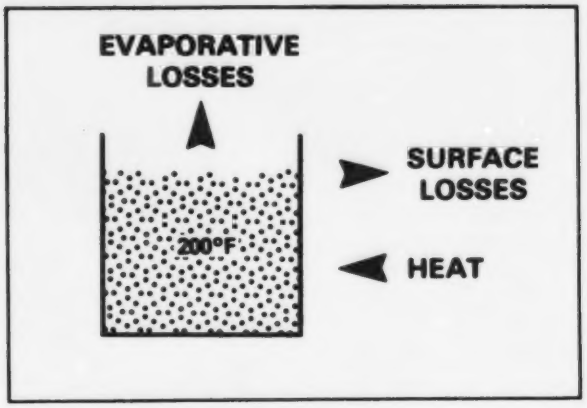
Most managers think they have a good "gut" feeling for general areas of energy inefficiency in plant processes. But often there is a great surprise as to where the major energy losses really do occur. These can only be revealed in a comprehensive energy audit.

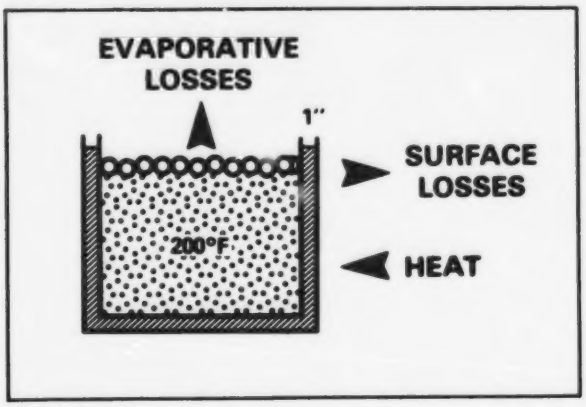
The process of conducting an energy audit is covered in some detail in the Guidebook to the OEC handbook series. However, there are

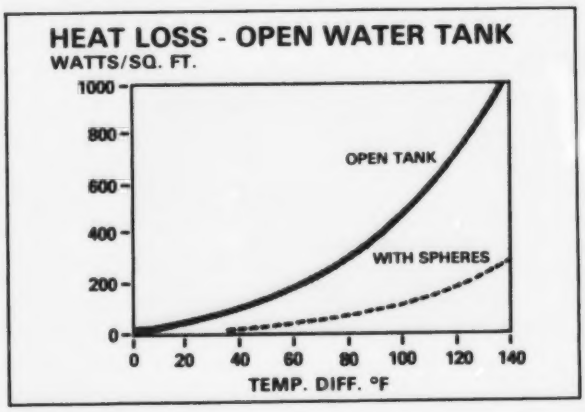
several basic steps to the process audit which should be mentioned:

- Look first at processing operations to establish priorities based on where substantial quantities of energy are involved.
- Wherever possible measure energy flows and process and effluent temperatures.
- Re-examine consultants' and manufacturers' specifications to see if these are being met.

Heat losses from process tanks







- Analyze each process using a simplified block diagram to show energy and material balances.

Perhaps most fundamental to a successful assessment of the system is a questioning (and cynical) mind. It is essential that questions be asked and the parameters of each process not simply be accepted as "the way things are" or "the way we do it around here".

Among the fundamental questions which must be asked are:

- Are process maintenance practices up to scratch? Or are they resulting in increased energy consumption?
- Can temperatures, flow rates or other conditions affecting energy consumption be lowered without affecting production rates or product quality?
- Could the equipment be better insulated to reduce heat losses?
- Can heat losses from the process be recirculated to preheat process input?
- Are there other sources of waste heat around the plant which can be used for preheating material for the process?
- Are there any waste materials which could be converted into useful energy?

Manufacturers of equipment, chemicals and additives can often be of great help here — and a little experimentation may be required before the ideal balance between product quality and energy conservation is struck — but energy savings will make the effort worthwhile.

With proper design, product quality does not have to be sacrificed to energy expediency. For example, in one case history, a one coat painting system was designed for tractor parts, saving considerable amounts of energy in drying ovens.

In the parlance of the day, "small is beautiful". The less processing that is done at high temperatures, the lower the energy requirements and the fewer the problems that will exist for disposal of the hot effluent. However, two factors in energy are temperature and time. Some processes operating at very high temperatures for short periods may use less energy than alternative processes at lower temperatures for longer times (e.g. Ultra High Temperature Milk).

Heat, and often high heat, is frequently a necessity for industrial processes and today's economics have made it a basic law of thermodynamics that "wherever there is heat there should be insulation".

Here, open baths for plating and other processes are an excellent example. Case histories in this booklet demonstrate graphically the potential uses for insulation on tank bottoms and sides and for the use of either a floating blanket of plastic balls or moveable rigid covers. Not only does a complete insulation system of this sort save substantial amounts of energy, it cuts down on evaporation — reducing water requirements and reducing the deleterious affects on both people and equipment of a moist ambient environment.

Insulation of another sort is involved with air curtains and other means of reducing steam and vapour losses from process equipment, without the need for excessive exhausts to create negative pressures inside the washer. Keeping in the vapour, in these examples (see case history), means keeping the heat in — and will save energy.

Air gases also often convey energy — and it is important to control their flow.

Waste not, want not

It goes without saying that an effort should be made in all processes to waste as little as possible. If effluent can be filtered and re-used as part of the process — so much the better. Great strides have been made recently in the use of reverse osmosis and other techniques which can greatly reduce the amount of process waste which once had to be trucked away for disposal. This is not the technology of ten years from now . . . investments can be justified today, in many cases, on the strength of the savings that can be made.

But even if the effluent doesn't incur the costs of trucking for disposal, why waste it — or use it on a once through basis — if it can be recirculated? The booklet in this series on "Steam Management" extols at some length the virtues of condensate recovery for boilers. And the same type of reasoning applies to process applications.

Among the commodities most often wasted needlessly, water probably heads the list. Heated water of all kinds is frequently flushed to sewer after one use. In many cases the water can be used directly in another process as feedwater. In others it can be used in a heat exchanger to extract much of the sensible heat before it's diposed of. In still others where it has gained a great deal of heat and heat is not required, it can be put through a cooling tower and re-used (see case history).

There are amazing parallels which can be drawn between water and energy conservation. Both commodities were once thought to be abundant and cheap and thus were wasted. Water has not yet made the "endangered species" list along with energy. But it's not far behind and smart business judgment — and in some cases municipal controls — dictate that it should be conserved wherever possible.

Heat recovery — the great frontier

Imagination is a great asset to anyone examining energy use in process applications. The range of remedial measures or new designs that are possible are almost boundless. And for each basic application, there are a hundred small modifications which may need to be made to meet the specific conditions of a given plant.

With the assumption that process equipment is well designed, maintained and operated, another major subject area — heat recovery — is opened up. In fact, its scope is so large that an attempt has not been made to cover it all in one booklet. To mention just a few, there are heat recovery schemes where flue gas heat is used to preheat building make-up air, where oven exhaust is used to preheat oven entering air, and where flash steam is used to heat air or a number of products. The list is a long one.

For the sake of organization, case histories on the subject have been divided up on the basis of the area they effect most directly to appear in booklets two, three, five or six in this series.

Those pertaining to flash steam or condensate recovery are generally in the "steam" booklet; those pertaining to space heating examples are generally found in the booklet on "Heating, Lighting and Air Conditioning"; those related to combustion are found in the "Combustion Control" booklet; etc. A look at the index is the best guide as to where to find information relevant to specific interests.

In this booklet, case histories generally pertain to heat recovery where heat is either taken from or supplied to industrial process. In addition, an attempt will be made to list the major generic types of heat recovery equipment now available on the market.

At the outset, though, it should be pointed out that the most efficient heat recovery systems are those where there is no heat exchange medium used. While certain heat exchangers can attain efficiency rates of 80 percent and more in given settings, none can compete with direct recycling when this can be accomplished.

Where, for example, clean flue gases from a dryer in a wash process can be ducted directly to the strip section to pre-dry metal parts, thermal efficiency gets as close to 100% as it can. Similarly, where hot air from any source can be filtered or cleaned by electrostatic precipitation and used to heat building air, efficiency will be greater than that attainable by heat recuperation using mechanical means.

This is particularly true, for example with cooling water from air compressors or spot welders which is most profitably used as feedwater for boilers, wash processes or other direct applications. And steam condensate is generally most economically returned to the boiler for recycling once it has given up its flash steam for use in low pressure steam systems or other applications.

For obvious reasons, though, not all sources of waste heat can be recirculated directly. In many cases, there are contaminants in the hot gas or liquid which cannot be removed simply or at low cost and heat reclaiming equipment is a necessity.

Options in heat recovery equipment

Industrial heat exchangers have many pseudonyms. They are sometimes called recuperators, regenerators, waste heat steam generators, condensers, heat wheels, temperature and moisture exchangers, and other names. Whatever name they many have, they all perform one basic function, the transfer of heat.

Heat exchangers are characterized as single or multipass gas to gas, liquid to gas, liquid to liquid, evaporator, condenser, parallel flow, counter flow, or cross flow. The terms single or multipass refer to the heating or cooling media passing over the heat transfer surface once or a number of times. Multipass flow involves the use of internal baffles. The next three terms refer to the two fluids between which heat is transferred in the heat exchanger, and imply that no phase changes occur in those fluids. Here the term "fluid" is used in the most general sense. But all these terms apply to nonevaporator and noncondensing heat exchangers.

The term evaporator applies to a heat exchanger in which heat is transferred to an evaporating (boiling) liquid, while a condenser is a heat exchanger in which heat is removed from a condensing vapor. A parallel flow heat exchanger is one in which both fluids flow in approximately the same direction whereas in counterflow the two fluids move in opposite directions. When the two fluids move at right angles to each other, the heat exchanger is of the crossflow type.

The principal methods of reclaiming waste heat in industrial plants make use of heat exchangers. In essence, a heat exchanger is a system which separates the stream containing waste heat and the medium which is to absorb it, but allows the flow of heat across the separation boundaries. The reasons for separating the two streams may be any of the following:

- A pressure difference may exist between the two streams of fluid. The rigid boundaries of the heat exchanger can be designed to withstand the pressure difference.
- In many, if not most, cases the one stream would contaminate the other, if they were permitted to mix. The heat exchanger prevents mixing.
- Heat exchangers permit the use of an intermediate fluid better suited than either of the principal exchange media for transporting waste heat through long distances. The secondary fluid is often steam, but another substance may be selected for its special properties.
- Certain types of heat exchangers, specifically the desiccant heat wheel, are capable of transferring humidity as well as heat. Vapors being cooled in the gases are condensed in the wheel and later re-evaporated into the gas being heated. This can result in improved humidity and/or process control, abatement

of atmospheric air pollution, and conservation of valuable resources.

The various names or designations applied to heat exchangers are partly an attempt to describe their function and partly the result of tradition within certain industries. For example, a recuperator is a heat exchanger which recovers waste heat from the exhaust gases of a furnace to heat the incoming air for combustion. This is the name used in both the steel and the glass making industries. The heat exchanger performing the same function in the steam generator of an electric power plant is termed an air preheater, and in the case of a gas turbine plant, a regenerator.

However, in the glass and steel industries, the word regenerator refers to two chambers of brick checkerwork which alternately absorb heat from the exhaust gases and then give up part of that heat to the incoming air. The flows of flue gas and of air are periodically reversed by valves so that one chamber of the regenerator is being heated by the products of combustion while the other is being cooled by the incoming air. Regenerators are often more expensive to buy and maintain than recuperators, and their application is primarily in glass melt tanks and in open hearth steel furnaces.

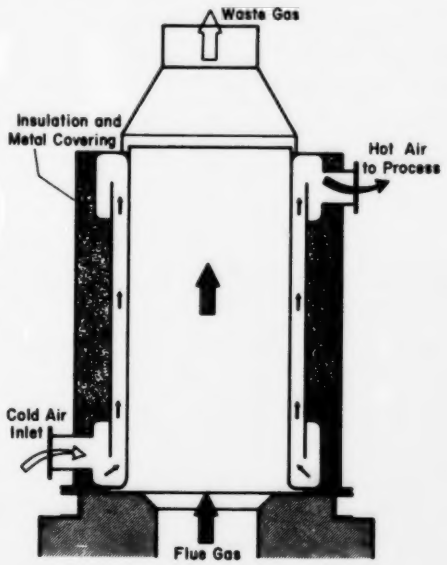
It must be pointed out, however, that although their functions are similar, the three heat exchangers mentioned may be structurally quite different as well as different in their principal modes of heat transfer. A more complete description of the various industrial heat exchangers follows later in this chapter and details of their differences will be clarified.

The specification of an industrial heat exchanger must include the heat exchange capacity, the temperature of the fluids, the allowable pressure drop in each fluid path, and the properties and volumetric flow of the fluids entering the exchanger. These specifications will determine construction parameters and thus the cost of the heat exchanger. The final design will be a compromise between pressure drop, heat exchanger effectiveness, and cost. Decisions leading to that final design will balance out the cost of maintenance and operation of the overall system against the fixed costs in such a way as to minimize the total. Advice on selection and design of heat exchangers is available from vendors.

The essential parameters which should be known in order to make an optimum choice of waste heat recovery devices are:

- Temperature of waste heat fluid
- Flow rate of waste heat fluid
- Chemical composition of waste heat fluid
- Minimum allowable temperature of waste heat fluid
- Temperature of heated fluid
- Chemical composition of heated fluid
- Maximum allowable temperature of heated fluid
- Control temperature, if control required.

Metallic radiation recuperator



Gas to gas heat exchangers

1. Recuperators

The simplest configuration for a heat exchanger is the metallic radiation recuperator which consists of two concentric lengths of metal tubing as shown.

The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which

now carries additional energy into the combustion chamber. This is energy which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading.

The saving in fuel also means a decrease in combustion air and therefore, stack losses are decreased not only be lowering the stack gas temperatures, but also by discharging smaller quantities of exhaust gas. This particular recuperator gets its name from the fact that a substantial portion of the heat transfer from the hot gases to the surfact of the inner tube take place by radiative heat transfer. The cold air in the annulus, however, is not affected by infrared radiation so that only convection heat transfer takes place to the incoming air.

As shown in the diagram, the two gas flows are usually parallel, although the configuration would be simpler and heat transfer more efficient if the flows were opposed in direction (or counterflow). The reason for the use of parallel flow is that recuperators frequently serve the additional function of cooling the duct carrying away the exhaust gases, and consequently extending its service life.

The inner tube is often fabricated from high temperature materials such as stainless steels of high nickel content. This gives a large temperature differential expansion, since the outer shell is usually of a different and less expensive material. And the mechanical design must take this effect into account. More elaborate designs of radiation recuperators incorporate two sections; the bottom operating in parallel flow and the upper section using the more efficient counterflow arrangement. Because of the large axial expansions experienced and the stress conditions at the bottom of the recuperator, the unit is often supported at the top by a free standing support frame with an expansion joint between the furnace and recuperator.

A second common configuration for recuperators is the tube type or convective recuperator. As seen in the schematic diagram, the hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in a direction normal to their axes.

If the tubes are baffled to allow the gas to pass over them twice, the heat exchanger is termed a two-pass recuperator; if two baffles are used, a three-pass recuperator, etc. Although baffling increases both the cost of the exchanger and the pressure drop in the combustion air path, it increases the effectiveness of heat exchange. Shell- and tube-type recuperators are generally more compact and have a higher effectiveness than radiation recuperators, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases.

The principal limitation on the heat recovery of metal recuperators is the reduced life of the liner at inlet temperatures exceeding 1093°C. At this temperature, it is necessary to use the less efficient arrangement of parallel flows of exhaust gas and coolant in order to maintain sufficient cooling of the inner shell. In addition, when furnace combustion air flow is dropped back because of reduced load, the heat transfer rate from hot waste gases to preheat combustion air becomes excessive, causing rapid surface deterioration. Then, it is usually necessary to provide an ambient air by-pass to cool the exhaust gases.

In order to overcome the temperature limitations of metal recuperators, ceramic tube recuperators have been developed, whose materials allow operation on the gas side to 1538°C and on the preheated air side to 1204°C on an experimental basis, and to 816°C on a more or less practical basis. Early ceramic recuperators were built of tile and joined with furnace cement, and thermal cycling caused cracking of joints and rapid deterioration of the tubes. Later developments introduced various kinds of short silicon carbide tubes which can be joined by flexible seals located in the air headers. This kind of patented design illustrated maintains the seals at comparatively low temperatures and has reduced the seal leakage rates to a few percent.

Earlier designs had experienced leakage rates from 8 to 60 percent. The new designs are reported to last two years with air preheat temperatures as high as 704°C, and much lower leakage rates.

An alternative arrangement for the convective type recuperator, in which the cold combustion air is heated in a bank of parallel vertical tubes

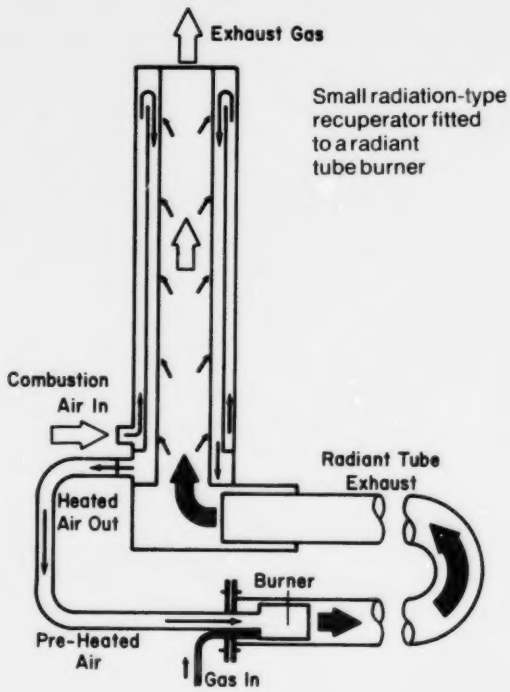
which extend into the flue gas stream, is also shown schematically. The advantage claimed for this arrangement is the ease of replacing individual tubes, which can be done during full capacity furnace operation. This minimizes the cost, the inconvenience, and possible furnace damage due to a shutdown forced by recuperator failure.

For maximum effectiveness of heat transfer, combinations of radiation type and convective type recuperators are used, with the convective type always following the high temperature radiation recuperator.

Although the use of recuperators conserves fuel in industrial furnaces, and although their original cost is relatively modest, the purchase of the unit is often just the beginning of a somewhat more extensive capital improvement program. The use of a recuperator, which raises the temperature of the incoming combustion air, may require purchase of high temperature burners, larger diameter air lines with flexible fittings to allow for expansion, cold air lines for cooling the burners, modified combusion controls to maintain the required air/fuel ratio despite variable recuperator heating, stack dampers, cold air bleeds, controls to protect the recuperator during blower failure or power failures, and larger fans to overcome the additional pressure drop in the recuperator. It is vitally important to protect the recuperator against damage due to excessive temperatures, since the cost of rebuilding a damaged recuperator may be as high as 90 percent of the initial cost of manufacture and the drop in efficiency of a damaged recuperator may easily increase the fuel costs by 10 to 15 percent.

The schematic diagram shows a radiant tube burner fitted with a radiation recuperator. With such a short stack, it is necessary to use two annuli for the incoming air to achieve reasonable heat exchange efficiencies.

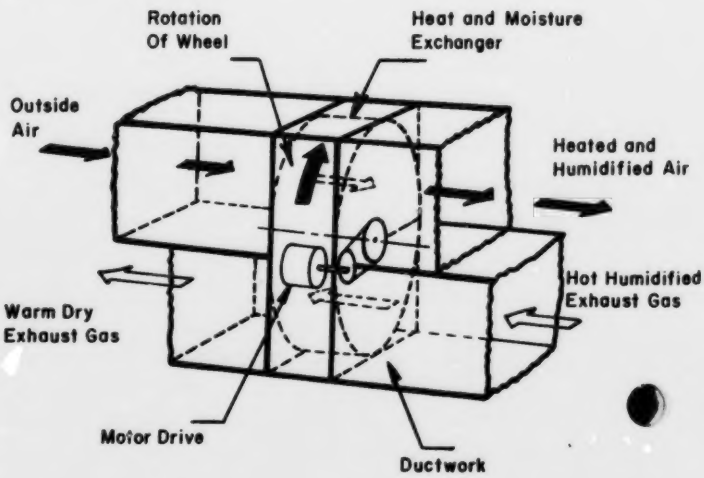
Recuperators are used for recovering heat from exhaust gases to heat other gases in the medium to high temperature range. Some typical applications are in soaking ovens, annealing ovens, melting furnaces, afterburners and gas incinerators, radiant-tube burners, reheat furnaces, and other gas to gas waste heat recovery applications in the medium to high temperature range.



2. Heat wheels

A rotary regenerator (also called an air preheater or a heat wheel) is finding increasing applications in low to medium temperature waste heat recovey. As shown in the sketch, it is a sizable porous disc, fabricated from material having a fairly high heat capacity, which rotates between two side-by-side ducts; one a cold air

Heat and moisture recovery using a heat wheel type regenerator



duct, the other a hot air duct. The axis of the wheel is located parallel to, and on the partition between the two ducts. As the wheel slowly rotates, sensible heat (and in some cases, moisture containing latent heat) is transferred to the material by the hot air and removed from the material by the cold air.

The overall efficiency of sensible heat transfer can be as high as 80 percent and heat wheels have been built as large as 12 ft in diameter with air capacities up to 60,000 cfm. Multiple units can be used in parallel. In very large installations such as those required for preheating combustion stations, the units are custom designed.

Heat wheels are available in four types. The first consists of a metal frame packed with a core of knitted mesh stainless steel or aluminum wire, resembling that found in the common metallic kitchen pot scraper; the second, called a laminar wheel, is fabricated from corrugated metal and is composed of many parallel flow passages; the third type is also a laminar wheel but is constructed from a ceramic matrix or honeycomb configuration. This is used for higher temperature applications with a present-day limit of about 871°C. The fourth variety is a laminar construction, but the flow passages are coated with a hydroscopic or dessicant material so that latent heat may be recovered. The packing material of the dessicant wheel may be any of a number of materials.

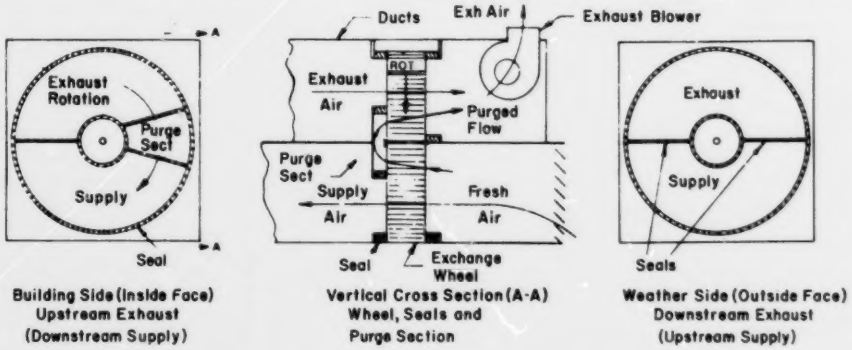
Most industrial stack gases contain water vapor, since water vapor is a product of the combustion of all hydrocarbon fuels and since water is introduced into many industrial processes and part of the process water evaporates as it is exposed to the hot gas stream. Each pound of water requires approximately 1000 Btu for its evaporation at atmospheric pressure, thus each pound of water vapor leaving in the exit stream will carry 1000 Btu of energy with it. This latent heat may be a substantial fraction of the sensible energy in the exit gas stream. A hygroscopic material such as lithium chloride readily absorbs water vapor and in a hygroscopic heat wheel, the hot gas stream gives up part of its water vapor to the lithium chloride coating; the cool gases which enter the wheel to be heated are drier than those in the outlet duct and part of the absorbed water is given up to the incoming gas stream. The latent heat of the water adds directly to the total quantity of recovered waste heat. The efficiency of recovery of water vapor can be as high as 60 percent.

Since the pores of heat wheels carry a small amount of gas from the exhaust to the intake duct, cross contamination can result. If this contamination is undesirable, the carryover of exhaust gas can be partially eliminated by the addition of a purge section where a small amount of clean air is blown through the wheel and then exhausted to the atmosphere, thereby clearing the passages of exhaust gas. The drawing illustrates the features of an installation using a purge section.

When operating with outside air in periods of high humidity and sub-zero temperatures, heat wheels may require preheat systems to prevent frost formation. When handling gases which contain water-soluble, greasy or adhesive contaminants or large concentrations of process dust, air filters may be required in the exhaust system upstream from the heat wheel.

One application of heat wheels is in space heating situations where unusually large quantities of ventilation air are required for health or safety reasons. As many as 20 or 30 air changes per hour may be required to remove toxic gases or to prevent the accumulation of

Heat wheel equipped with purge section to clear contaminants from the heat transfer surface



explosive mixtures. Comfort heating for that quantity of ventilation air is frequently expensive enough to make the use of heat wheels economical. In the summer season the heat wheel can be used to cool the incoming air from the cold exhaust air, reducing the air conditioning load by as much as 50 percent.

It should be pointed out that in many circumstances where large ventilating requirements are mandatory, a better solution than the installation of heat wheels may be the use of local ventilation systems to reduce the hazards.

Heat wheels are finding increasing use for process heat recovery in low and moderate temperature environments. Typical applications would be curing or drying ovens and air preheaters in all sizes for industrial and utility boilers.

3. Air Preheaters. (Parallel plate)

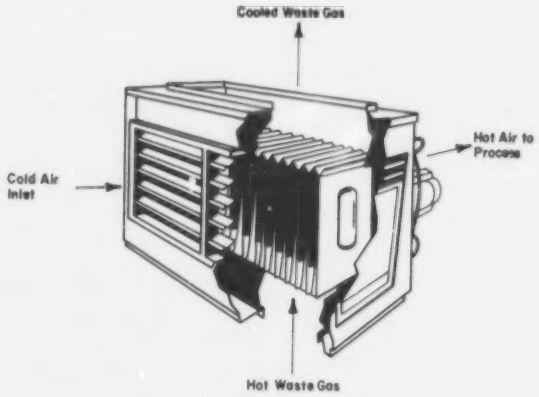
Passive gas to gas regenerators, sometimes called air preheaters, or baffle plate exchangers, are available for applications which cannot tolerate any cross contamination. They are constructed of alternate channels which put the flows of the heating and the heated gases in close contact with each other, separated only by a thin wall of conductive metal. They occupy more volume and are more expensive to construct than are heat wheels, since a much greater heat transfer surface area is required for the same efficiency.

One advantage, besides the absence of cross-contamination, is the decreased mechanical complexity since no drive mechanism is required. However, it becomes more difficutl to achieve temperature control with the passive regeneration and, if this is a requirement, some of the advantages of its basic simplicity are lost.

Gas-to-gas regenerators are used for recovering heat from exhaust gases to heat other gases in the low to medium temperature range. Among typical applications are:

- Heat recovery from building heating and ventilation systems
- Reduction of building air conditioner loads
- Heat recovery from steam boiler exhaust gases

A passive gas to gas regenerator



- Heat recovery from gas and vapor incinerators
- Heat recovery from baking, drying, and curing ovens
- Heat recovery from gas turbine exhausts
- Heat recovery from other gas-to-gas applications in the low through high temperature range

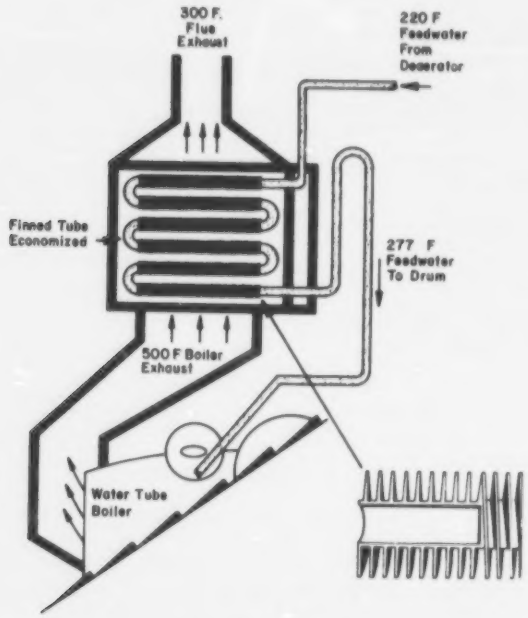
4. Heat pipe exchangers

The heat pipe is a heat transfer element that has only recently become commercial, but it shows promise as an industrial waste heat recovery option because of its high efficiency and compact size. In use, it operates as a passive gas-to-gas finned-tube regenerator. As can be seen in the drawing, the elements form a bundle of heat pipes which extend through the exhaust and inlet ducts in a pattern that resembles the structured finned coil heat exchangers. Each pipe, however, is a separate sealed element consisting of an annular wick on the inside of the full length of the tube, in which an appropriate heat transfer fluid is sealed.

Heat absorbed from hot exhaust gases evaporates the entrained fluid, at one end causing the vapor to move to the other end. The latent heat of vaporization is carried in the vapor to the cold end of the heat pipe located in the cold gas duct. Here the vapor condenses giving up its latent heat. The condensed liquid is then carried by capillary (and/or gravity) action back to the hot end where it is recycled.

Used as designed, the heat pipe is compact and efficient because the finned-tube bundle is inherently a good configuration for convective

Burned tube gas to liquid regenerator (economizer)



heat transfer in both gas ducts and the evaporative-condensing cycle within the heat tubes is a highly efficient way of transferring the heat internally. It is also free from cross contamination. Possible applications include:

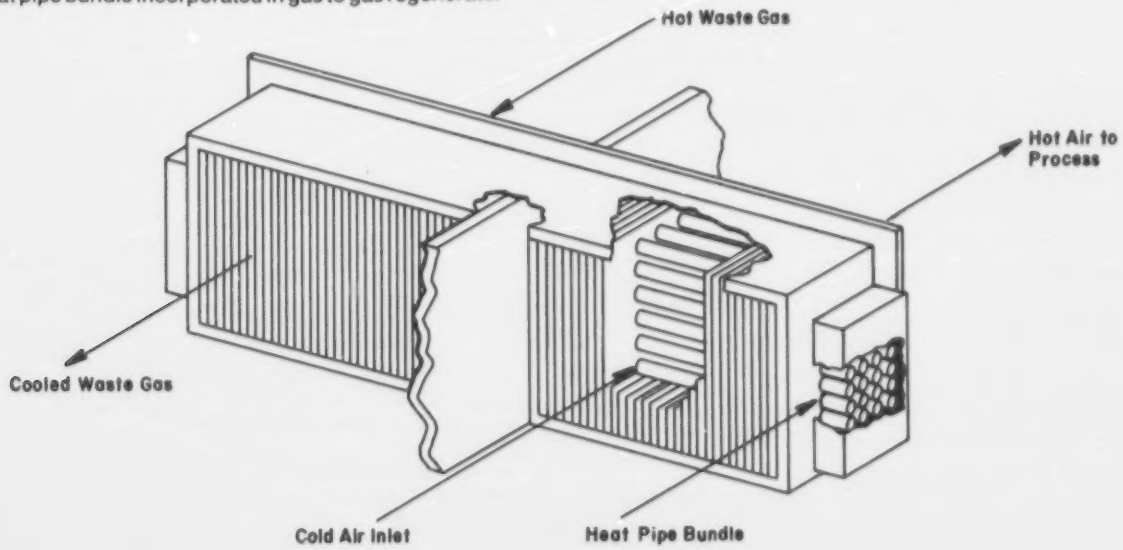
- Drying, curing and baking ovens (recycling waste heat).
- Reclamation of heat from water steam.
- Preheating combustion air from boilers.
- Air dryers.
- Brick kilns (secondary recovery).
- Reverberatory furnaces (secondary recovery).
- Reducing load in heating, ventilating and air conditioning systems.
- Cooling dies and bearings.
- Transferring engine exhaust to carburetor air intake.

Gas or liquid to liquid regenerators

1. Finned-tube Heat Exchangers

When waste heat in exhaust gases is recovered for heating liquids for purposes such as providing domestic hot water, heating the feedwater for steam boilers, or for hot water space heating, the finned-tube heat exchanger is generally used. Round tubes are connected together in bundles to contain the heated liquid and fins are welded or otherwise attached to the outside of the tubes to provide additional surface area for removing the waste heat in the gases. The drawing shows the usual arrangement for the finned-tube exchanger positioned in a duct and details of a typical finned-tube construction. This particular type of application is more commonly known as an "economizer." The tubes are often connected all in series but can also be arranged in series-parallel bundles to control the liquid side pressure drop. The air side

Heat pipe bundle incorporated in gas to gas regenerator



pressure drop is controlled by the spacing of the tubes and the number of rows of tubes within the duct.

Finned-tube exchangers are available prepackaged in modular sizes or can be made up to custom specifications from standard components. Temperature control of the heated liquid is usually provided by a bypass duct arrangement which varies the flow rate of hot gases over the heat exchanger. Materials for the tubes and the fins can be selected to withstand corrosive liquids and/or corrosive exhaust gases.

Finned-tube heat exchangers are used to recover waste heat in the low to medium temperature range from exhaust gases for heating liquids. Typical applications are hot water heating, heating boiler feedwater, hot water space heating, absorption-type refrigeration or air conditioning, and heating process liquids.

2. Shell and Tube Heat Exchanger

When the medium containing waste heat is a liquid or a vapor which can heat another liquid, the shell and tube heat exchanger must be used since both paths must be sealed to contain the pressures of their respective fluids. The shell contains the tube bundle, and usually internal baffles, to direct the fluid in the shell over the tubes in multiple passes. The shell is inherently weaker than the tubes so that the higher pressure fluid is circulated in the tubes while the lower pressure fluid flows through the shell.

When a vapor contains the waste heat, it usually condenses, giving up its latent heat to the liquid being heated. In this application, the vapor is almost invariably contained within the shell. If the reverse is attempted, the condensation of vapors within small diameter parallel tubes causes flow instabilities. Tube and shell heat exchangers are available in a wide variety of standard sizes with many combinations of materials for the tubes and shells.

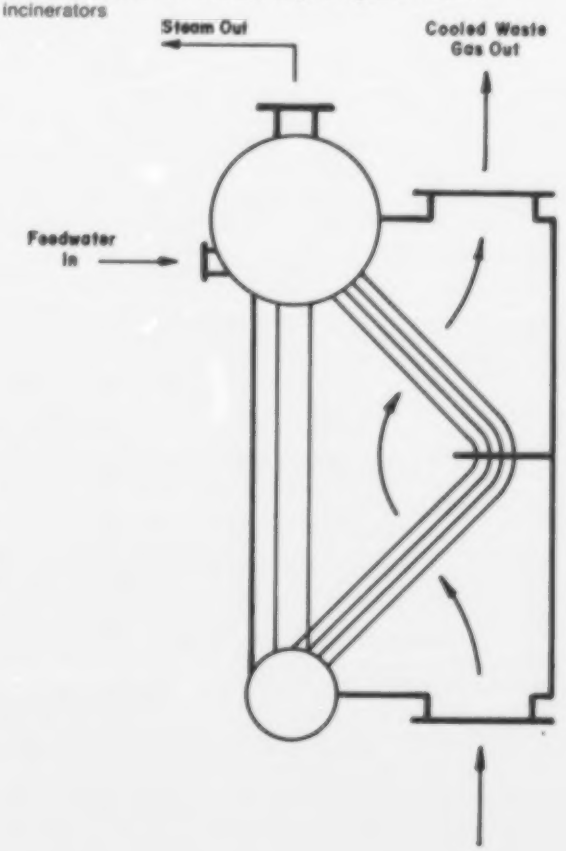
Typical applications include heating liquids with the heat contained in condensates from refrigeration and air conditioning systems; condensate from process steam; coolants from furnace doors, grates, and pipe supports; coolants from engines, air compressors, bearings, and lubricants; and the condensates from distillation processes.

3. Waste Heat Boilers

Waste heat boilers are ordinarily water tube boilers in which the hot exhaust gases from gas turbines, incinerators, etc., pass over a number of parallel tubes containing water. The water is vaporized in the tubes and collected in a steam drum from which it is drawn off for use as heating or process steam. The drawing indicates one arrangement that is used, where the exhaust gases pass over the water tubes twice before they are exhausted to the air. Because the exhaust gases are usually in the medium temperature range and in order to conserve space, a more compact boiler can be produced if the water tubes are finned in order to increase the effective heat transfer area on the gas side. The diagram shows a mud drum, a set of tubes over which the hot gases make a double pass, and a steam drum which collects the steam generated above the water surface.

The pressure at which the steam is generated and the rate of steam production depend on the temperature of the hot gases entering the boiler, the flow rate of the hot gases and the efficiency of the exchanger.

Waste heat boiler for heat recovery from gas turbines or incinerators



Should the waste heat in the exhaust gases be insufficient for generating the required amount of process steam, it is sometimes possible to add auxiliary burners which burn fuel in the waste heat boiler or to add an afterburner to the exhaust gas duct just ahead of the boiler.

Waste heat boilers are built in capacities from less than a thousand to almost a million cfm of exhaust gas and are typically used to recover energy from the exhausts of gas turbines, reciprocating engines, incinerators, and furnaces.

4. Gas and Vapor Expanders

Industrial steam and gas turbines are in an advanced state of development and readily available on a commercial basis. More recently special gas turbine designs for low pressure waste gases have become available; for example, a turbine is available for operation from the top gases of a blast furnace. In this case, as much as 20MW of power could be generated, representing a recovery of 20 to 30 percent of the available energy of the furnace exhaust gas stream. Maximum top pressures are of the order of 40 psig.

Perhaps of greater applicability are steam turbines used for producing mechanical work and for driving electrical generators. After removing the necessary energy for doing work, the steam turbine exhausts partially spent steam at a lower pressure than the inlet pressure. The energy in the turbine exhaust stream can then be used for process heat in the usual ways. Steam turbines are classified as back-pressure turbines, available with allowable exit pressure operation above 400 psig, or condensing turbines which operate below atmospheric exit pressures. The steam used for driving the turbines can be generated in direct fired or waste heat boilers. Among typical applications for gas and vapor expanders are:

- Electrical power generation and process steam.
- Compressor drives and process steam.
- Electric power generation and district steam heating.
- Fan drives and power generation.

The table on page 14 presents the collation of a number of significant attributes of the most common types of packaged industrial heat exchangers in matrix form. This matrix allows rapid comparisons to be made in selecting competing types of heat exchangers. The characteristics given in the table for each type of heat exchanger are: allowable temperature range, ability to transfer moisture, ability to withstand large temperature differentials, availability for retrofitting, and compactness and the allowable combinations of heat transfer fluids.

With regard to moisture recovery, it should be emphasized that many of the heat exchangers operating in the low temperature range may condense vapors from the cooled gas stream. Provisions must be made to remove those liquid condensates from the heat exhanger.

Liquid run-around system

One non-packaged system which is always custom designed to local conditions is the liquid run-around system. As shown in the diagram, the "run-around" involves two liquid-to-air exchangers, similar to the radiators on a car interconnected by two pipes. The circuit usually contains a glycol as a transfer medium kept flowing through the system by a pump. In this case, heat from exhaust air is being picked up by the glycol and transferred to the exchanger in the intake duct where it gives up its heat.

The run-around system requires piping and a constantly running pump and generally needs more attention than heat wheels, plate types or heat pipes. In addition, it can only transfer sensible heat and is generally less than 50% efficient.

However, if offers the great advantage of being usable where both the heat source and the heat requirement are physically separated from each other.

Many different applications are possible for the glycol run-around system capturing heat from both waste water or air streams. And the case history in this booklet describing an application at 3M of Canada in London, Ontario offers a particularly intriguing example of the results that can be generated with applied ingenuity using this system.

Heat reclaiming efficiency

Manufacturers often offer a single number to

express the efficiency of a typical heat recovery unit. However, in a given application, it is wise to remember that it is not always simple to calculate efficiency (particularly where latent and sensible heat transfer is involved) and that efficiency ratings for the same piece of equipment can vary up to 10 percent depending on relative temperature differences and volume flows.

The lesson? Heat recuperators have proven themselves efficient in industrial use, but the same savings will not result from two different applications, unless all conditions are exactly the same.

The heat pump

All of the four heat recovery systems discussed can be considered as straight "Btu exchangers" in that no matter what the efficiency of the unit, the temperature of the incoming fresh air or water will not quite reach the temperature of the

Operation and Application Characteristics of Industrial Heat Exchangers

SPECIFICATIONS FOR WASTE RECOVERY UNIT / COMMERCIAL HEAT TRANSFER EQUIPMENT	Low Temperature Sub-Zero - 250°F	Intermediate Temp. 250°F - 1200°F	High Temperature 1200°F - 2000°F	Recovers Moisture	Large Temperature Differentials Permitted	Packaged Units Available	Can Be Retrofit	No Cross-Contamination	Compact Size	Gas-to-Gas Heat Exchange	Gas-to-Liquid Heat Exchanger	Liquid-to-Liquid Heat Exchanger	Corrosive Gases Permitted with Special Construction
Radiation Recuperator			●		●	1	●	●		●			●
Convection Recuperator		●	●		●	●	●	●		●			●
Metallic Heat Wheel	●	●		2		●	●	3	●	●			●
Hygroscopic Heat Wheel	●			●		●	●	3	●	●			
Ceramic Heat Wheel		●	●		●	●	●		●	●			●
Passive Regenerator	●	●			●	●	●	●		●			●
Finned-Tube Heat Exchanger	●	●			●	●	●	●	●		●		4
Tube Shell-and-Tube Exchanger	●	●			●	●	●	●	●		●	●	
Waste Heat Boilers	●	●				●	●	●			●		4
Heat Pipes	●	●			5	●	●	●	●	●			●

1. Off-the-shelf items available in small capacities only.
2. Controversial subject. Some authorities claim moisture recovery. Do not advise depending on it.
3. With a purge section added, cross-contamination can be limited to less than 1% by mass.
4. Can be constructed of corrosion-resistant materials, but consider possible extensive damage to equipment caused by leaks or tube ruptures.
5. Allowable temperatures and temperature differential limited by the phase equilibrium properties of the internal fluid.

waste heat source.

One new development in heat recovery, the heat pump, has overcome this barrier by reclaiming Btu's and "stacking" them so that the reclaimed heat can be of a higher temperature than the waste medium — given an additional 40-50 percent contribution of electrical energy added to the exhaust heat.

Essentially, a heat pump works on a basic refrigeration cycle, in which an electrically driven compressor discharges hot, high pressure gas to a condenser where it becomes a liquid, giving up heat to the medium to be heated. As shown in the diagram, in the evaporator the liquid becomes a gas, absorbing heat from the exhaust air or waste medium.

With normal maximum exhaust temperatures of 46-54°C (work is underway on models with higher output temperatures), for every 1 Kwh put into the heat pump, 3 Kwh is received back in energy, giving a Coefficient of Performance (COP) of 3. Heat pumps are a significant development and will doubtless be a major part of the future of energy conservation.

As the temperature of the heat source drops, so does the COP of the heat pump. As a result, use is generally suggested only when the reclaimed temperature has to be higher than the waste heat temperature or possibly when supply and exhaust heat sources are in different locations and energy has to be added to the recuperated heat.

Creativity is the key

There are as many different processes as there are plants in Canada — and the opportunities for energy conservation measures are rife.

What is required is a creative approach — a willingness to break with past practice, without sacrificing practicality, for the sake of real dollar savings.

Two good examples of this type of thinking not mentioned in the case history section both deal in some way with cement. The first of these involves a new, more energy efficient "dry process" for making cement to be used by Inland Cement at a plant in Delta, B.C.

Under the conventional "wet process", raw materials are ground up and mixed with 32 to 39 percent water to form a slurry necessary for transport into the kiln. Here, the wet limestone and other ingredients can only receive the heat necessary to convert them into cement after the water has been driven off. The result is wasted energy and water — and a considerably larger kiln size requirement.

The new "dry process" eliminates water by using a preheat tower with four preheating stages — with heat supplied at each stage by exhaust from the cement kiln. Residual kiln exhaust will also be used to produce convection currents used to collect dust in roller mills on the site.

While it's a massive project, the company is convinced it will be profitable, given the energy intensiveness of an industry in which up to 3.5 million Btu's are consumed per ton of cement produced.

By coincidence, another recent process-related conservation development involved energy saving doors for plants that produced concrete blocks. Under the system manufactured in Canada by Phillipe Cousin Limited of Montreal, large kiln doors do not open wide to remove or insert racks while loading and unloading the kiln — losing up to 50 percent of the energy generated in the previous heating cycle.

With the new "pigeon hole" door plants, only one pallet at a time is inserted onto fixed racks inside the kiln. One small door is opened each time to inert "green" blocks and to remove the cured product.

Ideas like this are lurking behind process and combustion equipment in plants across Canada.

CASE HISTORIES

Air curtains replace exhausters on washer

The situation: A sheet metal parts washer using high pressure hot water/steam to degrease components at International Harvester's Chatham, Ontario plant used two 9,000-cfm exhausters to maintain a negative pressure inside the washer and prevent the escape of steam and water into the plant. Management realized that the 18,000 cfm exhaust, at temperatures between 34°C and 43°C, represented a significant and avoidable heat loss.

Action taken: The exhausters were removed and air curtains installed to prevent steam escaping into the plant.

Energy/dollars savings: 3800 MMBtu @ $2.00 MMBtu = $7,600/year.

Cost of improvement: $4,000.

Recommendation: Consider eliminating exhausts from washers and other plant processes wherever possible.

Boiler combustion air preheated by flue gas recovery

The situation: At the Toronto bakery of George Weston Limited, 1,200 cfm of 216°C boiler exhaust was being vented to atmosphere, carrying with it considerable amounts of usable heat. A consultant was asked to explore possible heat recovery.

Action taken: A plate-type heat exchanger was installed to preheat boiler combustion make-up air.

Energy savings: Estimated at 1,450 Mcf/year. Savings would be greater if building operated year round. During summer months when heating loads are minimal, the boiler operated at only 1/3 to ½ capacity.

Dollar savings: 1,450 Mcf/year @ $2.00/Mcf = $2,900/year

Cost of improvement: $1,850.

Recommendation: Low cost options exist to recover heat from flue gases for various purposes within the plant. Explore them.

Coating oven heat recovery utilizes incinerator exhaust

The situation: Four of the large coating ovens at American Can of Canada Limited's Hamilton plant were used to bake a protective coating onto the interior of can cylinders and in the process produce volatile solvent vapours which environmental authorities insisted be removed through an incineration process. Management saw an obvious opportunity to capitalize on these clean 649°C incinerator exhausts as a source of heat (previously supplied by natural gas) for re-injection into the coating ovens.

Action taken: A heat recovery system was installed on the coating ovens to allow controlled amounts of incinerator exhaust to be drawn down into the six zone control areas within the oven—and via a system of controls and dampers to maintain internal oven temperatures at desired levels up to 218°C.

Energy savings: (per oven).

Annual gas consumption without recovery = 43,176 Mcf/yr
Annual gas consumption with recovery = 26,124 Mcf/yr
Savings = 17,052 Mcf/yr

Dollar savings: (per oven)
17,052 Mcf @ $2.00/Mcf = $34,104/year.

Cost of improvement: $56,000 (heat recovery only).

Recommendation: Look to recovery systems to capitalize on incinerator flue gases. Bear in mind future technological developments when evaluating the economics of the investment required. American Can carried out these

improvements with the full knowledge that water based interior coatings (which would eliminate the need for incinerators and thus incinerator-produced heat) were in an early stage of development—along with a system of ultra-violet electric drying which was predicted to reduce energy requirements and size of the oven considerably.

Compressor cooling water for ammonia condensors and other uses

The situation: Labatt's Breweries realized that sending an average of 100 gpm (144,000 gals/day) of 26°C water down the drain represented a significant energy loss—particularly given their water requirement for ammonia condensors, boiler make-up water, and other uses.

Action taken: The company installed piping to take compressor cooling water to the boiler (40,000 gals/day) and the ammonia condensors (20,000 gals/day). City water previously used for both purposes averaged about 4°C. Compressor cooling water is about twice as hot and, therefore, requires less gas-fired heat to bring it to the required heat of 104°C.

Energy savings: Reductions in natural gas and water consumption total nearly $15,000/year.

Cost of improvement: $26,000.

Recommendations: Explore other uses than boiler feedwater for compressor and spot welder cooling waters or other clean water containing heat which would otherwise be wasted. For the 80,000 gals/day still being routed to drain, Labatt's hopes to find other uses including hose stations to wash floors, roof sprays to reduce heat load during the summer, and supply to a large storage tank, as a secondary water supply for fire control systems.

Cooling tower reduces refrigeration water consumption

The situation: Dough mixers at the Toronto plant of George Weston Limited have a requirement for cool water to chill the freon used in the refrigeration process. 17,000,000 gals/year were being used on a once through basis. A consultant advised the company of potential savings if this water could be recycled using a cooling tower.

Action taken: A cooling tower was installed which, because 16°-19°C cooling water is required for plant refrigeration units, can be used for eight months of the year—with city water required for the remainder of the time.

Water savings: Estimated at 17,000,000 gals X 8/12 = 11,333,000 gals/yr.

Dollar savings: 11,333,000 gals @ $.6675/k gal. (plus sewer charge) = $8,600/year

Cost of improvement: $12,500 with an annual operation cost of $1,500/year

Recommendation: Investigate the use of cooling towers to reduce cooling water demand from city sources. In some areas by-laws forbid once through water systems. This may be a trend to watch.

Ducting recovers exhaust for dryer preheating

The situation: Sangamo Limited's Toronto plant were forced to put in a new electrically-heated drying oven in the metal parts washing line. Rather than continuing to vent 3,000 cfm dryer exhaust to the atmosphere, it was decided to capture this 88°C air and utilize it to pre-dry metal parts in the drip section of the process.

Action taken: Using internal staff, 4 feet of ducting was installed to take the hot air from the dryer exhaust to the drip section and from there to atmosphere.

Energy savings: An estimated seven percent reduction in electric consumption due to lower drying times in the oven.

Dollar savings: estimated at $180/yr

Cost of improvement: $60.

Recommendation: Low cost alternatives to make use of waste heat from oven exhaust exist in many plants. As in this case, savings may be relatively small, but so are the investments required.

Economizer performs well at a glass plant

The situation: A glass plant, anticipating a possible fuel shortage, began exploring fuel conservation programmes.

Action taken: Effective heat transfer seemed to be an obvious need so their small packaged boiler was retrofitted with an economizer to heat boiler feedwater. The boiler was a two-pass gas-fired boiler of typical design, operating at 120 psig saturated (177°C) and producing both heat and process steam. It had 2,000 sq. ft. of heating surface an original rating of 200 hp. A custom-designed economizer was provided and installed. The manufacturer initially sized the unit to have an expected pickup of 640,000 Btu/hr. After a reasonable time in use, it was determined that the pickup averaged more than 1,000,000 Btu/hour.

Energy savings: Based on 5 days/week, 50 weeks/year, and 24 hours/day, a calculated 6×10^9 Btu/year are received by the economizer. Ignoring weekend savings, actual energy saved by the economizer (at 80% boiler efficiency) was 6,600 MMBtu in one year of operation . . . equivalent to 6,600 Mcf gas.

Dollars savings: At $2.00/Mcf for gas, savings amount to (6,600) ($2.00) = $13,200/year

Installation costs: Cost for second unit installation was $6,046 U.S. Thus the payback period was well under one year.

Recommendation: Many industrial applications offer opportunities for heat recovery — look into these options for your plant.

Economizer recovers waste heat for space heating in a dairy

The situation: A dairy was building a new warehouse and conventional gas heating was not available due to a gas shortage.

Action taken: It was decided to recover heat from boiler flue gases which were discharged to the atmosphere. The general design specifications were:

1. installation of a finned hot water coil in the stack breeching.
2. installation of a pump to circulate water to the fan coils in the warehouse.
3. a conventional hot water system to be used in the warehouse.
4. water from the finned coil to be automatically diverted to the new boiler feedwater preheater when warehouse heating requirements were satisfied.
5. provision to be made to automatically divert flue gases to the atmosphere when more heat was available than could be used.

Energy savings: The heat available from the flue gases, captured at 75% recovery, amounted to 4,875 MMBtu/year.

Dollar savings: At $2.00/Mcf, (4,875 Mcf) ($2.00) = $9,750/year.

Cost of improvement: The recovery system cost $17,340.

Recommendation: Look to heat recovery applications in your plant. While the primary need was heating the warehouse, additional benefits were derived by incorporating a feedwater preheater in the system. This made the total recovery system $9,040; more expensive than an electrical heating system, but the incremental cost was recovered in less than 2 years because of savings in operating cost. All stack recovery systems must ensure that gas temperatures remain high enough to avoid condensation and/or acid corrosion.

Filtration recovers waste solutions

The situation: At the Cambridge, Ontario plant of Butler Metal Products, the company operates a five-stage wash process for metal stampings. Every two weeks wash tanks are dumped so that the holding tank will not become contaminated. This effluent (which is 98% water with oil and drawing compounds) is removed by tank truck and incinerated at a cost of approximately $10,000 per year.

Action taken: The company is exploring the possibility of a continuous filtration system which will remove dirt and oil from the cleaning solution and reduce markedly the amount of solution carted away.

Energy savings: None directly; but the waste incineration is extremely energy intensive and

accounts for a large proportion of the costs associated with disposing of 2200 gal. of solution at two week intervals.

Dollar savings: Not available; however, it is assumed that the payback period will be less than two years.

Cost of improvement: $10,000 including hardware and installation.

Recommendation: Consider filtration systems or other means to prolong the life of process solutions and to reduce external haulage and/or incineration charges.

Floating ball blankets cuts heat loss on insulated tank

The situation: The management of Canadair Limited were concerned about surface heat loss from an otherwise well-insulated tank containing 64,000 lbs. of sodium dichromate at 94°C Before taking action, controlled tests were carried out in which steam required to keep the tank up to temperature was metered with and without a ball blanket covering. Steam consumption in the latter case was cut by more than two-thirds.

Action taken: A layer of 2-inch diameter polypropylene balls was put in place on the tank surface, resulting in lower evaporation, greatly reduced heat loss and considerably shorter heat-up time after tank heating is shut off for weekends or holidays.

Energy savings:

Steam requirement without blanket = 1820 lbs/hr (533 kw)

Steam requirement with blanket = 570 lbs/hr (167 kw)

Reduction = 1250 lbs/hr = 6.9 gal/hr heating oil.

Dollar savings: 6.9 gal/hr × 24 hrs × 5 day/wk × 47 wk/yr = 38,916 gal/yr @ .35/gal = $13,620/year.

Water savings of approximately $100/yr were also experienced.

Flue gases recovered from ovens preheats air

The situation: At the Toronto bakery of George Weston Limited, consultants identified an opportunity for energy saving by capturing waste heat from flue gases from bread ovens for use in preheating oven air. Depending on conditions 200-500 cfm of flue gas at temperatures from 260°C-341°C were available from 2 gas-fired ovens using a total of five burners. Make up air was being ducted in from outside at an average temperature of 7°C.

Action taken: Five small plate-type heat exchangers were installed (one for each burner) using flue gases to preheat oven air to 188°C-244°C, depending on flue gas temperature.

Energy savings: Estimated at 2,650 Mcf/year

Dollar savings: 2,650 Mcf/year @ $2.00/Mcf = $5,300/year

Cost of improvement: $7,250.

Recommendation: Look for heat recovery applications where flue gases can be used to preheat oven or kiln make-up air.

A glycol run-around system recovers heat

The situation: 3M Canada Limited recognized the availability of large volumes of waste heat in the form of high temperature process exhaust and flash steam from high pressure condensate. The potential for heat recovery existed in preheating process oven entering air and in preheating building make-up air during the winter months; however, due to the large quantities of air involved, the distance between heat sources and heat users, and the availability of flash steam for heat recovery an air-to-air system was thought not to be suitable. Because of contaminants process exhaust air could not be recirculated.

Action taken: The company implemented a glycol run-around system which, although less efficient than an air-to-air system, had the advantage of lower initial cost and space requirements (no room existed for large duct runs) and the ability to recover heat from flash steam.

In the integrated system, three of the four heat transfer elements belong to a single processing unit. That is, heat is recovered from oven exhaust air and also from flash steam which is released from high pressure condensate from steam coils used to heat the oven entering air. This heat is

then transferred to the oven entering air before it enters the steam coils. The fourth heat transfer element—preheating of building make-up air operates only during the heating season although during that period it is the predominant heat user in the system.

Energy savings: the equivalent of 170,000 gal/yr of Bunker "C".

Dollar savings: 170,000 gal/yr @ $.35 gal = $59,500/yr.

Cost of improvement: $150,000.

Recommendation: Do not allow what appear to be physical barriers within the plant to stand in the way of heat recovery systems. 3M's experience with this particular system has shown that overheating of the building make-up air occurs in all but the coldest weather due to the quantity of heat available in the glycol. As a result, the company has subsequently installed a three-way valve and automatic temperature control at the make-up air glycol coils, to maintain make-up air at the desired temperature and to divert waste heat to the oven entering air where it can best be used.

Greater digester blow heat recovery saves oil

The situation: St. Anne-Nackawic Pulp and Paper Company had for some years operated a relatively small heat exchanger to recover heat from condensate from pulp digesters. Under the system condensate at 100 psig (laden with some cooking liquor and fibres) is vented to an accumulator tank at atmospheric pressure where it formed a considerable amount of flash steam which was utilized in a plate-type heat exchanger to heat river water from a low of 2°C (winter temperature) to 82°C-88°C for use in washing pulp for the bleach plant.

Given the increasing cost of fuel oil to generate steam and the amount of heat still being wasted due to the size limitations of the heat exchanger, it was realized that increased heat exchanger capacity would pay dividends.

Action taken: The company installed another plate-type heat exchanger 60 percent larger than the first one, and used both in parallel.

Energy savings: Steam reduction due to additional heat exchanger = 25 MMBtu/hour.

Dollar savings: 25 MMBtu/hr × 6000 hrs/yr × $2.00/MMBtu = $300,000/year.

Cost of improvement: $175,000 (Dcf rate of return—170%/year)

Recommendations: Many industrial processes offer opportunities for heat reclamation from spent liquids using a variety of heat exchangers. Look for potential applications.

Heat conserved from dryer exhaust

The situation: The outside air intake and exhaust stack for a high temperature drying system are located within 15 feet of each other on the roof of the 3M Canada plant in London, Ontario. For the energy conservation committee, it seemed an ideal situation for an air-to-air heat recovery system since only air was involved and the lengths of duct run were minimal. Available as a source of heat was 12,000 cfm of dryer exhaust which, depending on the process, ran about 94°C. Because of contaminants, the air could not be recycled.

Action taken: The company installed a bank of parallel plate heat exchangers to heat dryer make-up air (slightly less than 12,000 cfm since the dryer "runs negative") using the hot dryer exhaust. In winter, air from the heat exchanger averages 64°C while in the summer it approaches 94°C. In both cases it is further heated by steam to the 150 + 0°C required dryer inlet temperature.

Energy savings: Reduction of steam heating requirements for dryer make-up air, taking into account the efficiency of the heating system and the efficiency of steam generation, saved the equivalent of 33,000 gal/yr of Bunker "C".

Dollar savings: 33,000 gal/yr @ $.35 gal = $11,550/year.

Cost of improvement: Not available; however, the project had a payback period of less than 2 years.

Recommendation: Explore direct recycling of dryer and other heated exhausts first, but where air contaminants and other factors prohibit direct recirculation, investigate the use of heat exchangers (the regenerative wheel, and heat pipe are two of the other types available) to capture waste heat from exhaust streams. The

parallel plate heat exchanger offers the advantage of being modular in construction and permits flexibility of building up, reducing, or re-using components of the heat recovery system elsewhere in the plant. Note that the efficiency of this type of heat exchanger increases with difference in temperature between intake and exhaust gases.

Heat-pipe regenerator preheats make-up air in rubber vulcanizing

The situation: Unable to obtain additional energy needed for expansion of vulcanization and other steam process facilities, a rubber company turned to heat recovery equipment as a means of saving enough energy to handle the proposed expansion.

Action taken:

1. A new thermal recovery unit was installed to replace the old steam-heated preheat coil.
2. A new 125-hp boiler was installed to provide higher pressure and additional steam to meet processing requirements.
3. Two old 30-hp vertical upright boilers were retired and the natural gas they used was applied to the new boiler.

The new thermal recovery unit was basically two heat exchangers connected with a series of heat pipes. Each heat pipe was a self-contained, closed system which transported heat from source to sink with very little temperature drop. Actual operation depended on vapour heat transfer and capillary action. Thermal energy transfer was very efficient since it was essentially an isothermal process.

Energy savings: The installation was completed in July 1973 and has operated trouble-free since then. The annual savings in energy are calculated to be 3,200 Mcf of natural gas (or 3.2 billion Btu). It should be noted that this case was a low temperature application, the exhaust air from which heat was recovered being at 34°C.

Dollar savings: At $2.00/Mcf, total savings are $6,400.

Cost of improvement: Costs are proprietary information. Critical point is that, in addition to monetary savings, the installation made heat recovered available to be used elsewhere, thereby allowing for the expansion.

Recommendation: Heat pipes are an attractive heat recovery option for many applications. See booklet text for a discussion of various heat recovery methods.

Heat recovered from boiler continuous blowdown

The situation: 3M Canada realized an opportunity to make full use of latent heat in boiler continuous blowdown water to heat both feedwater in the deaerator and boiler make-up.

Action taken: A system was devised in which 9.5 MM lbs/yr of boiler continuous blowdown water (drawn off just below water level on the steam drum) is passed into a flash tank. 1.6 MM lbs/yr of flash steam is separated from the water and used to heat the feedwater in the deaerator—supplemented by low pressure live steam. The remaining 8.7 MM lbs/yr of water leaving the flash tank passes through a float and thermostatic trap, and then through a shell-and-tube heat exchanger where heat is transferred into the boiler make-up water. Blowdown water is finally discharged to drain at relatively low temperatures (16°-38°C).

Energy savings: On an annual basis, the system saves the company the equivalent of 19,000 gal/yr of Bunker "C" oil.

Dollar savings: 19,000 gal/yr @ $.35/gal = $6,650/year

Cost of improvement: Using all new equipment, $12,000. Because of the non-process related nature of the job, the Company was willing to accept the three year payback. (given energy prices at that time)

Recommendation: Investigate the use of boiler continuous blowdown water as an economical source of waste heat. The 3M system has proven to be relatively simple, reliable and maintenance free. Its critical point is the strainer on the blow down line ahead of the trap and heat exchanger. Due to the high concentration of suspended solids in the blowdown water, the strainer basket tends to plug quite rapidly and must be serviced frequently.

Heat recovered from textile waste water

The situation: Management of a textile mill

realized that there were major potential energy savings available from recovery of hot waste water from griege preparation ranges used for continuous fabric washing. Before energy conservation measures were implemented, 360 gpm of water at 160°F from the continuous washing operation was being discharged to a drain.

Action taken: The company installed a counterflow heat exchanger to preheat the 360 gpm of cold inlet water (yearly average temperature 63.3°F) using the wastewater as a source of heat. The heat exchanger was equipped with automatic back flushing to reduce the fouling problem characteristic of textile processes.

Energy savings: Based on a heat recovery factor of 58 percent and operation 4440 hr/yr: Savings = 360 gpm × 10 lb/gal × (160 − 63.3)°F × 60 min/hr × 4440 hr/yr × 1 Btu/lb°F × 0.58 = 45,000 MMBtu/yr.

Dollar savings: 45,000 Mcf @ $2.00 Mcf = $90,000/year.

Cost of Improvement: Assuming a five year capital recovery period, estimated annual amortization cost of the 10 MMBtu/hr heat exchanger plus the installation cost = $6,000/yr.

Recommendation: Evaluate the feasibility of heat recovery from all plant hot waste streams. Selection of proper counterflow heat exchange equipment for a particular system is important—recognizing the potential for excessive maintenance due to fouling problems.

Heat recovery saves energy in hydrocarbon incinerator

The situation: Solvent hydrocarbons from lithographic printing and subsequent baking of steel sheets for caps and closures at a can company posed potential air pollution problems. A third can line was to be installed and, while the two existing lines had fume incineration, there was no provision for heat recovery from the incineration. Primary specifications for the waste heat and incineration system included:

1. complete hydrocarbon destruction from baking
2. direct-flame incineration
3. operational economy

Action taken: Oven exhaust fumes were directed from the process gas forced-draft fan through the inside of the tubes of a recuperative type heat exchanger where they were preheated before entering the combustor. The exchanger was a two-pass cross-counterflow system with gases entering at up to 162°C and leaving at up to 497°C to enter the combustor. Incinerated hot gases leave the direct-flame combustor, pass over the outside of the heat exchanger tubes, and exit to the stack as cleaned, cooled gases at about 447°C.

Energy savings: Based on a process flow rate of 8,500 cfm and 6,000 hours/year of operation, the savings in gas consumption amounted to 54%.

Dollar savings: at a cost of $2.00/Mcf, savings amounted to $80,000 per year.

Cost of improvement: The total cost of the incineration-heat recovery system, including installation and research work, was $100,000.

Recommendation: Consider recuperation for oven exhaust fumes.

Heat recovery saves energy, water in sterilizing retorts

The situation: At the Leamington, Ontario plant of H. J. Heinz Limited, large retorts are filled with jars of products to be sterilized. Since cold water can not be added to the retorts without thermoshock, 2280 gallons per cycle of city water first had to be heated from its average 10°C temperature to 77°C before being added to the retorts. Addition of steam then brought the water temperature to 116°C whereupon hot water was gradually removed and sent to drain and cold water gradually added in a cooling cycle which reduced water temperature in the retorts to 32-38°C.

Management was aware that large amounts of hot water removed during the cooling cycle were being wasted, with a consequent excessive consumption of steam to heat cold city water for the next retort sterilizing cycle.

Action taken: The company installed a 6,000 gallon tank complete with automatic timers, air

operated valves and made necessary tie-ins to the reclaim line from each retort, so that hot water could be recovered from the retort during the cooling cycle and used for the next heating cycle.

Energy savings: Assuming that 60 percent of the 2,280 gal/retort cycle will not have to be reheated (i.e. 40 percent make-up), 2,280 × .60 = 1,368 gal/cycle (approx.). Steam savings =

$$\frac{120°F \times 1{,}370 \text{ gal/cycle} \times 10 \text{ lbs/gal}}{1{,}000 \text{ Btu/lb}} =$$

1,644 lbs/cycle.

Dollar savings: @ $2.50/M lbs. steam = $4.11 cycle × 4,200 cycles/yr = $14,364/year.

Cost of improvement: $28,500. This yielded a dcf rate of return on investment of 42% and a payback period of under 2 years.

Recommendation: Clean hot water flushed to drain always represents a major loss of heat which could be utilized in the plant. Look at every possible use for hot water before allowing it to carry Btu's to the sewer.

Heat wheel reduces energy costs in a paint shop

The situation: State law required a complete air change in a paint shop at 2-minute intervals. At the same time, air movement at the paint spray station had to have a minimum velocity of 120 ft./min./sq. ft. of booth opening. Also, maintenance of a 24°C temperature in the paint shop during the winter was desired. It was determined that 90% of the wasted sensible heat in the exhausted air could be recovered and used to preheat incoming air for the paint shop.

Action taken: Exhaust air was collected into a common duct system—the sources were paint spray booths, fume incinerators on bake ovens, a washer vent, and a drying oven. The final design was an energy recovery package mounted on the plant roof with an 8-ft. diameter heat wheel as the heart of the system. The wheel was rotated by a small electric motor. Blended exhaust air entered at 108°C through one side of the wheel and outside air at ambient temperature passed through the other side. The sensible heat exchanged was used to provide the 24°C primary heating requirement. Exhaust air in excess of that needed for the heat exchange was by-passed around the wheel. Three standard cycles are possible: the energy recovery cycle, the recirculation cycle, and the ventilation cycle.

Energy savings: The ventilation requirements had to be met; if they had been met without the heat recovery system, an additional 55,380 gals. (U.S.) of propane per year would have been required.

Dollar savings: At $.42/U.S. gal., (55,380) ($.42) = $23,260/year.

Cost of improvement: Not available.

Recommendation: Look to heat wheels or other heat exchangers to recover waste heat from plant exhausts.

Low temperature chemicals reduce spray wash energy consumption

The situation: Spray wash operations for metal parts at the Toronto plant of Carrier Air Conditioning (Canada) Ltd. operated at temperatures approaching 70°C — meeting the requirements for detergents and chemicals used in the five-stage system (two water rinse stages). It was proposed that low temperature chemicals could be purchased at the same low cost and allow substantial savings in gas-fired heating for water for the system.

Action taken: Stages 1 and 3 of the process (detergent wash and conversion coating) were converted to low temperature products usable in water temperatures averaging 44°C. Stage 2 (water rinse) could then be lowered to the same operating temperature.

Energy saving: Using the formula: Pump capacity (gpm) × 60 min/hr × 10 lb/gal × degree drop = Btu/hr savings.
For each stage affected, it was determined that total hourly energy savings = 2,390,010 Btu.

Dollar savings: Based on 24 weeks per year operation and reduced consumption of natural gas in the boiler = $4,589.

Cost of improvement: Nil. Cold water chemicals cost slightly less than those formerly used.

Recommendation: Explore the use of low temperature chemicals and detergents for spray, immersion and coil coating applications of metal parts. In addition to savings in gas consumption, reduced temperature operations offer lower water consumption (less evaporation at lower temperatures), electrical savings (reduction in exhaust fan capacity), reduced maintenance on heating coils, space savings (frequently one boiler and associated fuel storage can be eliminated), and greater safety to workers not exposed to the chance of burns from hot solutions.

Process water heated with flue gas heat

The situation: A candy manufacturer recognized the potential for energy savings by using 15,000 lb/hr at 316°C from two oil-fired boilers to add heat to process water currently heated by an oil-fired system.

Action taken: A waste heat recovery system was installed in the stack of the two boilers (each rated at 7500 lb/hr exhaust) to cool flue gas steams to 150°C and to add this heat to process water from the water heater.

Energy saved: Recoverable energy through the waste heat system was: 15,000 lb/hr × 0.26 Btu/lb °C × (316-150)°C = 647,400 Btu/hr.

An equivalent amount of energy was saved in the operation of the hot water heater = (50 gpm from 10°C to 82°C).

As a result of the heat recovery installation, outlet temperatures from the water heater were reduced to 56°C with the extra 8°C added through the 1.17 MMBtu/hr recovered from boiler exhausts.

Dollar savings: Operating 6000 hr/yr:
1.17 MMBtu/hr × 6,000 hr/yr × $2.00 MMBtu (approx.) = $14,000/yr.

Recommendation: Pursue the possibility of using waste flue gas heat as a method of producing hot water. In order to avoid corrosion problems, exhaust should not be cooled below 150°C and water entering the heat exchanger should have a minimum temperature of 52°C.

Radiation recuperator heats building air in automatic transmission plant

The situation: Tests were conducted on two identical bent-tube batch furnaces in an automatic transmission plant. One furnace remained standard and the other was equipped with recuperators.

Action taken: The recuperators were of standard design and operated to extract energy from hot flue gases and transfer this recovered energy to incoming cold air. Both furnaces were equipped with gas meters to measure total volume and rates of gas consumption.

Test particulars include:
–2.0-2.5% Oxygen in exhausts (10% excess air);
–Set point temperature, 829°C.
–Load approximately 500 lbs.
–Heating cycle (set point temp. recovery).
–33 mins. for standard furnace.
–34 mins. for recuperator furnace.
–Soaking time.
–59 mins. for standard furnace.
–58 mins. for recuperator furnace.

Energy saved: Operating with pilots, 6 days/week, twelve 1½ hr. cycles per day, and all other times at idle, the gas consumed by the standard batch furnace is 4.5 MMcf/yr. Recuperation saves 860 Mcf per year, or 19% fuel, in one year. Without pilots, the recuperated furnace saves about 914 Mcf/year.

Dollar savings: (860 Mcf) ($2.00/Mcf) = $1,720/year.

Cost of improvement: A new furnace installation, where recuperators could be installed as the furnace is built, cost $4,950 for the recuperators in the U.S.

Recommendation: Look to recuperators or other heat exchangers to preheat building make-up air.

Rinse tank controllers, aeration save water

The situation: Engineers in one of Sangamo Limited's plants realized that considerable

amounts of water were being wasted by uncontrolled supply to rinse tanks in the plating operation.

Action taken: The company decided on a two-pronged program of rinse tank controllers and aeration to cut down on water consumption yet prevent excessive contamination in the tanks. As part of the system, conducting sensors, preset for allowable level of contamination in the tanks, are attached to a master solenoid control. As water is drawn into the tank, air is automatically provided into the tank through perforated PVC water lines — assuring that contamination is evenly distributed through the tank and that the sensors are not "fooled" by local concentrations of contaminants.

Water savings: 24,600,000 gal/yr.

Dollar savings: 24,600,000 gal/yr @ 6.91 cents per 100 gal. = $17,000/yr.

Cost of improvement: $3,600 materials + $900 labour = $4,500.

Recommendation: Continual supply of water to rinse tanks incurs unnecessarily high water bills. Automated systems offer a low-cost option to reduce water consumption and generate an attractive return on investment.

Tank cover modifications promote use, energy savings

The situation: Canadair Limited, Montreal had built two insulated steel covers for a pair of 95 sq. ft. salt baths heated constantly to 493°C. The covers were designed to cut down on the considerable surface loss of heat and water to the plant air but due to their weight, sectional nature and inability to be lifted by crane, were not being put in place by employees when tanks were not in use. (Due to infrequent use of the baths, full covers were preferable to a ball blanket covering.)

Action taken: A steel frame for the covers was designed and built with hooks which allowed it to be picked up in one piece and put in place using a crane. The covers are now in place whenever the tanks are not in use.

Energy savings: Based on a mean usage of the covers 18 hrs/day every day of the year:
Previous heat loss = 421,325 Btu/hr (123 Kw)

Present heat loss = 126,398 Btu/hr (37 Kw)

Reduction = 294,927 Btu/hr (86 Kw)
Additional small savings on water consumption were also attained.

Dollars savings: 294,927 Btu/hr × 18 × 365 = $1.94 MMMBtu/yr ÷ 3,412 Btu/Kwh: 568,581 Kwh/yr @ $.025/Kwh = $14,197/year

Recommendation: for those applications where heated tanks are open infrequently consider the use of a lid rather than a floating ball blanket. At Canadair a lid reduced heat loss by 70 per cent. Reduced power for tank heating proved to be the largest single contributor to reducing the plant's peak electrical demand.

Twin insulation conserves plating tank heat

The situation: Heated plating tanks (165°F) in the Toronto plant of Sangamo Limited were not insulated against surface heat loss or loss of heat energy through the walls and bottom of the tanks. An energy-conscious conservation committee realized the opportunity to insulate the tanks to save energy and at the same time improve air quality in the plating department through reduction of evaporation.

Action taken: Following an experimental program on one tank in which they metered electrical consumption before and after insulation, the company embarked on a program to insulate all 19 of the plant's tanks. One inch urethane foam was applied to the exterior of the tanks and clad in an outer sheet of .030 inch aluminum. A layer of ½-inch polypropylene balls was added to cover more than 90 percent of the surface area of each tank.

Energy savings: Eliminated 50% of measured 35,520 Kwh/yr. loss (per tank) = 17,760 kwh/yr.

Dollar savings: 17,760 Kwh @ $.025/kwh = $444/year.

Cost of improvement: $280 per tank.

Recommendation: Look to tank insulation and plastic balls or other inert floating material to cut down on overall tank heating losses. Applicable in a wide variety of processes, the plastic balls are available in a range of sizes (10mm to 100mm diameter) and materials (polypropylene and high and low density polyethylene) to match

particular process requirements.

Vapour loss reduced with polystyrene chips

The situation: A small chrome plating operation realized that it had a heat loss problem due to evaporation from its four open-top 18 sq. ft. tanks. Three of the tanks contained either copper, nickel or chromium solutions. The fourth was used for water rinse. All were heated four days/wk. 8 hr/day using electrical immersion heaters (total capacity 36 Kw) to temperatures ranging from 38°C to 66°C. Evaporation heat loss was increased by agitation in one of the tanks during plating operations and by forced ventilation in the overall area.

Action taken: Plant engineers covered the exposed liquid surface of the plating tanks with (2 inch x 2 inch) expanded polystyrene chips.

Energy savings: Heat loss was reduced from about 450 watts/sq. ft. to about 35 watts/sq. ft. Annual savings: 72 sq. ft. × (450-35) W/sq. ft. × 1 kw/1000W × 32 hr/wk × 50 wk/yr = 48,000 Kwh/yr.

Dollar savings: 48,000 Kwh/yr × $.025 KWh = $1,200/yr.

Cost of improvement: $450.00.

Recommendation: Consider the possibility of reducing evaporation losses from any heated, open top vessel by covering the surface of the liquid with floating inert material. Many types of foam material and hollow beads or balls are available, in a variety of plastic materials, depending on the temperature and chemical make-up of the liquid.

Waste heat is recovered from refinery stack gases

The situation: At the Sun Oil refinery in Sarnia, Ontario, the company had as its objective recovery of heat from flue gases being vented to atmosphere at temperatures for 399-454°C. Each heater or boiler had its own stack.

Action taken: A common duct work was used to combine the different flue gas outlets—with the combined flue gas stream sent to an economizer (heat exchanger) where heat was recovered by transferring it to boiler feed water to generate steam. The economizer flue gas was discharged to the atmosphere through a new stack.

The duct work and economizer were designed for a minimum friction drop compatible with the draft produced by the stack. Instrumentation and flue gas analyzers were provided at each heater and boiler outlet, to allow for proper combination control.

Economizer feedwater at 58,600 lb/hr is preheated to 94°C to minimize the temperature difference between the water and flue gas. This results in a reduction of the heat transfer area for a given heat transfer rate. A direct duct around the economizer to the stack is provided to allow for economizer maintenance.

Energy saved: Combined flue gas temperature entering the economizer is 399°C with an outlet temperature of 271°C. The heat recovered is calculated at 20 MMBtu/hr.

20 MMBtu/hr × 24 × 365 = 175,200 MMBtu/yr; Bunker "C" fuel = 185,000 Btu/Imp. Gal.

Dollar savings: 20 MMBtu/hr = 950,000 gal/yr @ ¢.35/imp. gal. Bunker "C" = $332,500/year.

Cost of improvement: $210,000.

Recommendation: Look to flue gases as a ready source of waste heat. Installations do not have to be of this size to be both practical and economical.

Waste heat recovered from pollution control equipment

The situation: Management of a metal finishing plant had added an incineration unit to a large paint curing oven in order to discharge only clean air to the atmosphere. Upon examination, it was decided that substantial energy savings could be made by recovering heat from incinerator flue gases. The incinerator was designed to accept up to 28,000 cfm of 371°C exhaust gas from the finishing oven—increasing the heat of this gas in the incinerator to 760°C by natural gas and the heat of combustion of the solvent vapour.

Action taken: Instead of exhausting hot clean air from the incinerator, exhaust is now passed to a heat exchanger to raise the temperature of oven

exhaust before it enters the incinerator—reducing the amount of natural gas needed for incineration. On leaving the heat exchanger, the clean exhaust air is sent to a waste heat boiler, producing 50 psi steam for general plant use. The total energy utilized is about 50 per cent of that generated by the incinerator (40 per cent in the heat exchanger and 10 per cent in the boiler).

Energy savings: Assuming operation of the incinerator at 75% of design capacity: Energy produced = 28,000 cfm × 0.0807 lb/cf × 60 min/hr. × (1400-700)°F × .28 Btu/lb °F × .75 = 20 MMBtu/hr.

At 50% utilization of this waste heat: Annual energy saving = 20 MMBtu/yr × 6000 hr/yr × .50 = 60,000 MMBtu/yr.

Dollar savings: 60,000 MMBtu/yr = 60 MMcf/yr @ $2.00 Mcf = $120,000/year

Cost of improvement: Not available

Recommendation: Clean air requirements may make more widespread the installation of equipment to recover or destroy solvent vapours from finishing ovens and spray booths. If incineration is used for this purpose in your plant, consider methods to recover waste heat from the operation.

Tips for saving money through process design and heat recovery

Process design

1. Schedule baking times of small and large components to minimize use of energy.
2. Use vapor recompression design in distillation processes.
3. Use "side draw" principle in distillation column design.
4. Use continuous equipment which retains process heating conveyors within the heated chamber.
5. Use direct flame impingement or infrared processing for chamber type heating.
6. Convert from indirect to direct firing.
7. Convert from batch to continuous operation.
8. Use shaft type furnaces for preheating incoming material.
9. Convert liquid heaters from underfiring to immersion or submersion heating.
10. Minimize unessential material in heat treatment processes.
11. Change product design to reduce processing energy requirements.
12. Reduce scrap production.
13. Upgrade obsolete or little used equipment.
14. Reduce process temperatures to the lowest level consistent with product quality.
15. Conserve hot water that would otherwise be flushed to sewer (e.g. compressor cooling water).
16. Utilize floating balls or chips to minimize heat loss on open process tanks.
17. Insulate process tanks.
18. Use rinse tank controllers to minimize water consumption.

Heat Recovery

1. Use the overhead condenser to generate steam from condensates in a distillation process.
2. Use hot flue gases in radiant heater for space heating ovens, dryers, etc.
3. Use heat in flue gases to preheat products or material going into ovens, dryers, etc.
4. Use hot process fluids to preheat incoming process fluids.
5. Use hot flue gases to preheat wastes for incinerator boiler.
6. Use "waste" heat from hot flue gases to generate steam for processes or consider selling excess steam.
7. Use "waste" heat from hot flue gases to heat space conditioning air.
8. Use "waste" heat from hot flue gases to preheat combustion air.
9. Use engine exhaust heat to make steam.
10. Recover fuel value in polluted exhaust air.
11. Recover fuel value in waste by-products.
12. Use flue gases to heat process or service water.
13. Use oven exhaust for space heating.
14. Use recovered heat from lighting fixtures for useful purpose; i.e., to operate absorption cooling equipment.
15. Use flue gas heat to preheat boiler feedwater.
16. Recover "waste" solutions through filtration or treatment.

SI USAGE

Derived SI Units Having Special Names

Quantity	Unit	Formula	Symbol
Frequency	hertz	s^{-1}	Hz
Force	newton	$kg \cdot m/s^2$	N
Pressure or Stress	pascal	N/m^2	Pa
Energy or Work	joule	N·m	J
Power	watt	J/s	W
Electric charge	coulomb	A·s	C
Electric potential	volt	W/A	V
Electric resistance	ohm	V/A	Ω
Electric conductance	siemens	A/V	S
Electric capacitance	farad	C/V	F
Magnetic flux	weber	V·s	Wb
Magnetic flux density	tesla	Wb/m^2	T
Inductance	henry	Wb/A	H
Luminous flux	lumen	cd·sr	lm
Illuminance	lux	lm/m^2	lx

Common Equivalents and Conversions

Approximate Common Equivalents
1 in. = 25 mm
1 ft. = 0.30 m
1 yard = 0.91 m
1 mile = 1.6 km
1 sq. in. = 6.5 cm^2
1 sq. ft. = 0.09 m^2
1 sq. yd. = 0.84 m^2
1 acre = 0.40 ha
1 cu. in. = 16 cm^3
1 cu. ft. = 28 dm^3
1 cu. yd. = 0.76 m^3
1 quart (liq) = 1.1 ℓ
1 gallon = 4.5 ℓ
1 oz. (Avdp.) = 28 g
1 lb. (Avdp.) = 0.45 kg
1 hp (UK) = 0.746 kW
1 lbf. = 4.4 N
1 psi = 6.9 kPa

Some Other Derived SI Units

Quantity	Unit	Symbol
Area	square metre	m^2
Volume	cubic metre	m^3
Velocity-angular	radian per second	rad/s
Velocity-linear	metre per second	m/s
Acceleration-angular	radian per second squared	rad/s^2
Acceleration-linear	metre per second squared	m/s^2
Density (mass per unit volume)	kilogram per cubic metre	kg/m^3
Moment of force	newton metre	N·m
Viscosity-dynamic	pascal second	Pa·s
Thermal conductivity	watt per metre kelvin	W/(m·K)
Thermal flux density, Irradiance	watt per square metre	W/m^2
Thermal capacity or Entropy	joule per kelvin	J/K
Permeability	henry per metre	H/m
Permittivity	farad per metre	F/m
Thermal resistance (R value)	square metre kelvin per watt	$m^2K \cdot w$
Energy density	joule per cubic metre	$J \cdot m^3$

SI PREFIXES

Multiplying Factor	Prefix	Symbol
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deca	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

Some Non-SI Units Used with the SI

Unit	Symbol	Value in SI Units
minute	min	1 min = 60 s
hour	h	1 h = 3600 s
day	d	1 d = 86 400 s
degree (of arc)	°	$1^\circ = (\pi/180)$ rad
minute (of arc)	′	$1' = (\pi/10\,800)$ rad
second (of arc)	″	$1'' = (\pi/648\,000)$ rad
litre	l or ℓ	1 ℓ = 1 dm^3 = 10^{-3} m^3
tonne	t	1 t = 10^3 kg = 1000 kg
hectare	ha	1 ha = 10 000 m^2

HOW TO ORDER

The Enersave Series of Industrial Energy Conservation Manuals

The Enersave set of ten industrial energy conservation manuals is available for $5.45 (including cost of binder, postage and handling) by completing the order form and sending with your cheque or money order to:

Master Mailers
P.O. Box 9705, Terminal Ottawa
Ottawa, Ontario K1G 3Z4

A6

Make remittance payable to:

Master Mailers
P.O. Box 9705, Terminal Ottawa
Ottawa, Ontario, Canada
K1G 3Z4

Name: _____

Title: _____

Name of Firm: _____

Address: _____

City: _____

Province: _____ Postal Code: _____

If individual copies of one or more of this series are required for special distribution by your firm, please make your request in writing to:

Office of Energy Conservation
580 Booth St. 17th Floor
Ottawa, Ontario
K1A 0E4